# *Quantum Structure Based IR Detector R&D at Acreo*

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# Outline

- *Acreo* – the Swedish industrial research institute within electronics-optics-communication
- *IMAGIC* development programme – an overview
- Infrared imaging – high performance and low-cost
  - QWIPs
  - QDIPs
  - InAs/InGaSb superlattices
  - Sb-based coupled QD superlattices (CDIPs)
  - QWs and QDs for microbolometers
- Summary

# Contributing researchers at Acreo/IRnova/KTH/LiTH

Jörgen Alverbro, IRnova
Carl Asplund, IRnova
Urban Halldin, IRnova
Bernhard Hirschauer, IRnova
Henk Martijn, IRnova

Linda Höglund, Acreo
Qin Wang, Acreo
Bertrand Noharet, Acreo
Mattias Hammar, KTH
Oscar Gustafsson, KTH
Staffan Hellström, KTH
Per Olof Holtz, Linköping Univ.

Christian Vieider, Acreo
Per Ericsson, Acreo
Stanley Wissmar, Acreo
Henry Radamsson, KTH
Wlodek Kaplan, Acreo

Susan Savage, Acreo

and many others at the participating companies

# Acreo

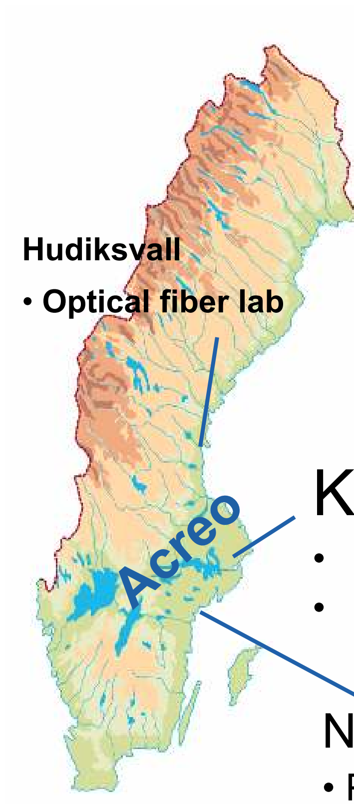
***Electronics – Optics – Communication Technology***

***Acreo*** part of ***Swedish ICT*** - Sweden's Industrial Research Institute within ICT (Information & Communication Technology)

- **Technical research**
- **Contract R&D**
- **Production**
- **Promote spin-off companies and industrial growth**

***Spin-off companies:***
***Total 30 companies during the last 10 years***
***With a turn over of 100 M€, 2007:***

***Within Imaging:***
***IRnova***




**Hudiksvall**

- **Optical fiber lab**

Kista Electrum

- **Nanoelectronics**
- Electrum Laboratory

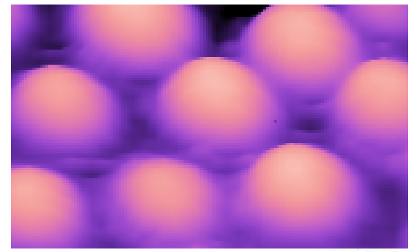
Norrköping

- Printed electronics
- CMOS design

# Nanoelectronics Technology

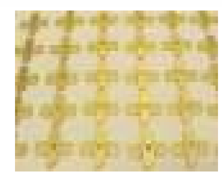
## Materials & Processes

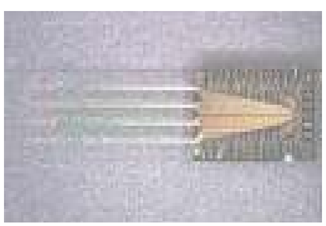
- **GaAs, InP and SiC based epitaxy**
- **Quantum nanomaterials, QWs and QDs**
- Semiconductor processing - Si, SiC, GaN, GaAs, InP
- MEMS incl quartz and polymers processing
- Flip-chip bonding - arrays & precision



## Devices & Modules

- **Detector arrays - Imaging sensors (IR, X-ray)**
- Power transistors & diodes
- Arrays of electroabsorption modulators - SLM
- Optical packaging - Microbenches
- Medical sensors



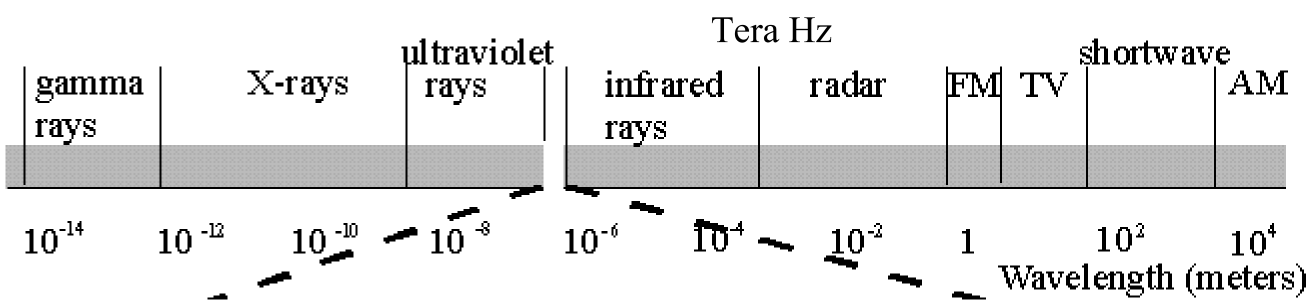


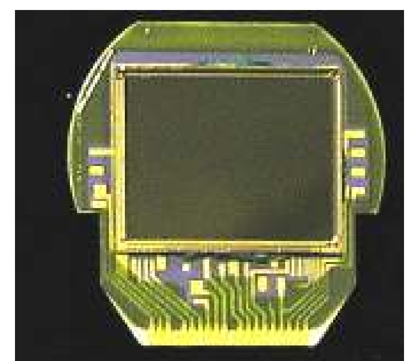
# IMAGIC – Imaging Integrated Components

Making the invisible visible!

## A Centre of Excellence for imaging devices and systems

**The development and realisation of next-generation digital imaging systems for non-visible wavelengths**



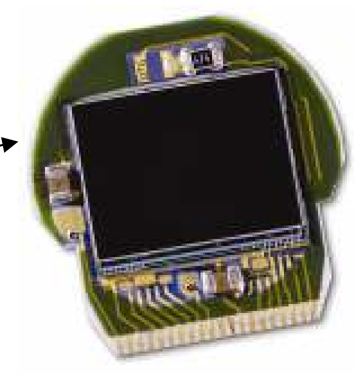



# Goal of IMAGIC

**IMAGIC should promote growth for the participating companies, based on unique research competence**

**Internationally reknown CE within imaging and imaging devices**

- At least three of the system prototypes developed within IMAGIC should be concluded to have commercial potential (5 years after IMAGIC startup)
- ***Development of key components: image sensors***
- ***R&D on novel detector materials***
- Design of readout electronics



## Infrared imaging – high performance, and low-cost

- QWIPs
- QDIPs
- InAs/InGaSb superlattices
- Sb-based coupled QD superlattices (CDIPs)
- QWs and QDs for microbolometers

# From Research to Product
# - IR imaging (high performance/cooled)

## QWIP - (Quantum Well Infrared Photodetector)

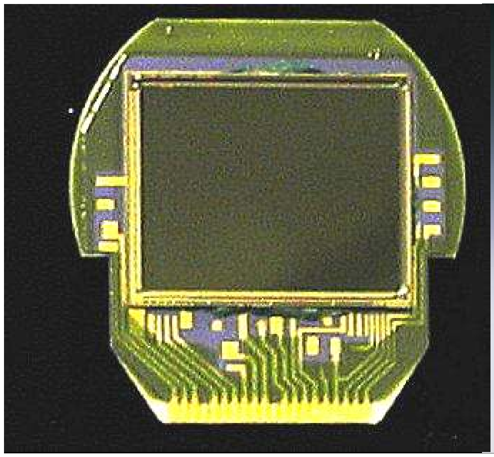
*A Sensor for Thermal Infrared Imaging*

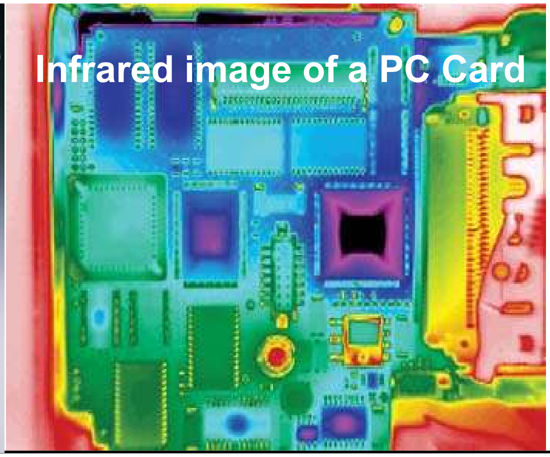
Properties

- 320x240 pixels, 640x480 pixels
- Chip size: 14x11 or 18x14 mm
- Temperature resolution < 0.03 Kelvin

Development by Acreo

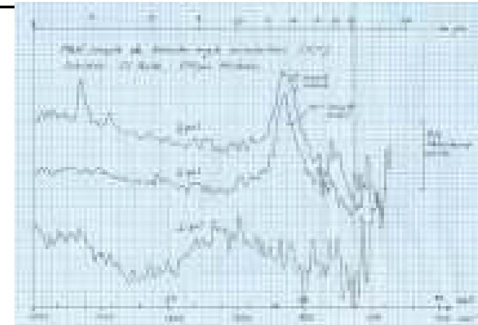
Produced and further developed by IRnova (an Acreo startup)

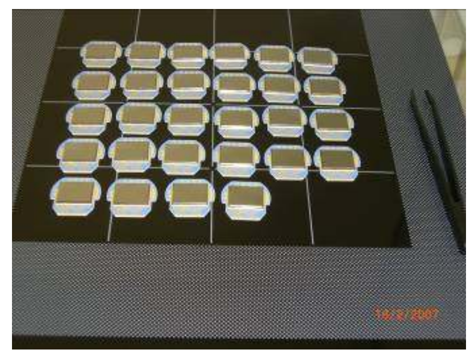


# QWIP
# – Quantum Well Infrared Photodetectors

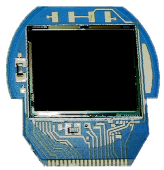
- From basic research to production:
  - •80’s: basic research
  - •90’s: development
  - •00’s: production
  - •Spin off company IRnova from research institute in 2007
- Development and production of high-end image sensors for infrared applications
- In house production
- High quality IR detector solutions adapted to specific application needs



**Capability of thousands of FPA’s /year**

# IRnova Business



⇒

IR-detector
FPA
(Focal Plane Array)

Cooled Module
DDCA
(Detector Dewar Cooler Assembly)

A/D card

PreAMP

Software

Proxy electronics

⇒

Manufacturers of
IR Camera/Systems

## High-performance IR

Next steps in development:

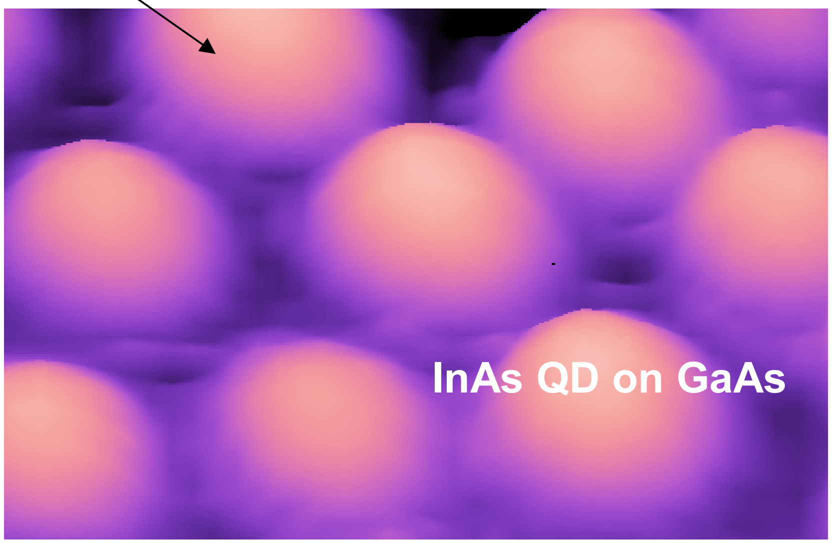
- Faster response
- Higher sensitivity
- Higher operating temperature

Possible solutions

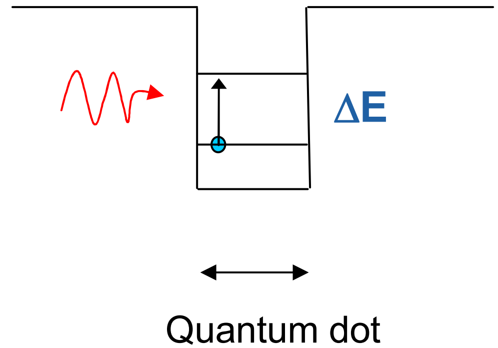
- QDIPs
- Sb based superlattices
- Sb based quantum dot structures

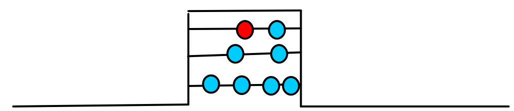
# Quantum Dot structures
# Status: Simple detectors produced

Quantum dots form potential wells which can trap electrons and holes



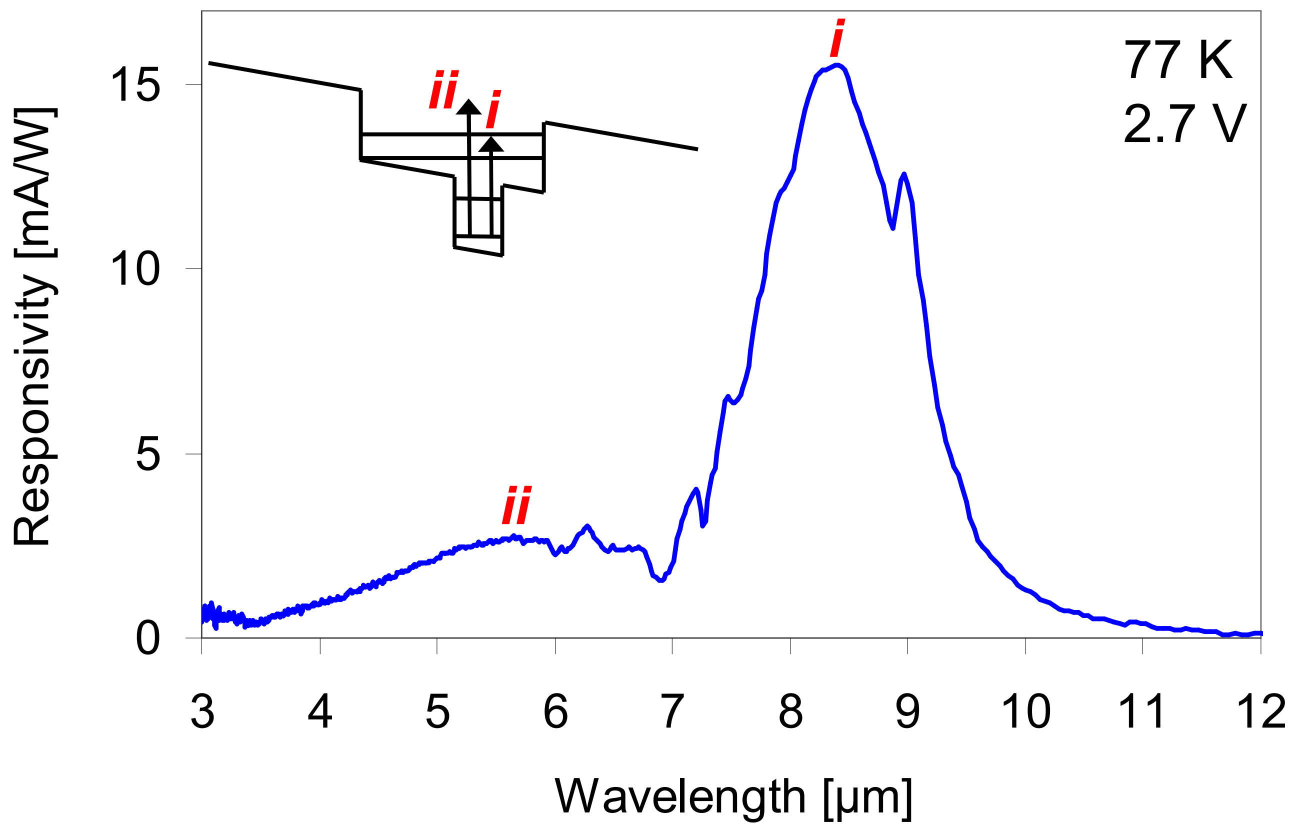

Fabricated by gas phase epitaxy - MOVPE



Prospects of lower dark current due to the 3D-confinement of carriers. Possibilities for higher operating temperature, resulting in a cheaper camera system

# DWELL QDIPs (Dot in a Well IR photodetectors) – typical results




InAs-QDs
GaAs matrix

cooperation with Linköping Univ.

# Antimony based superlattice detector (Sb-SL)
# Status: One pixel detectors

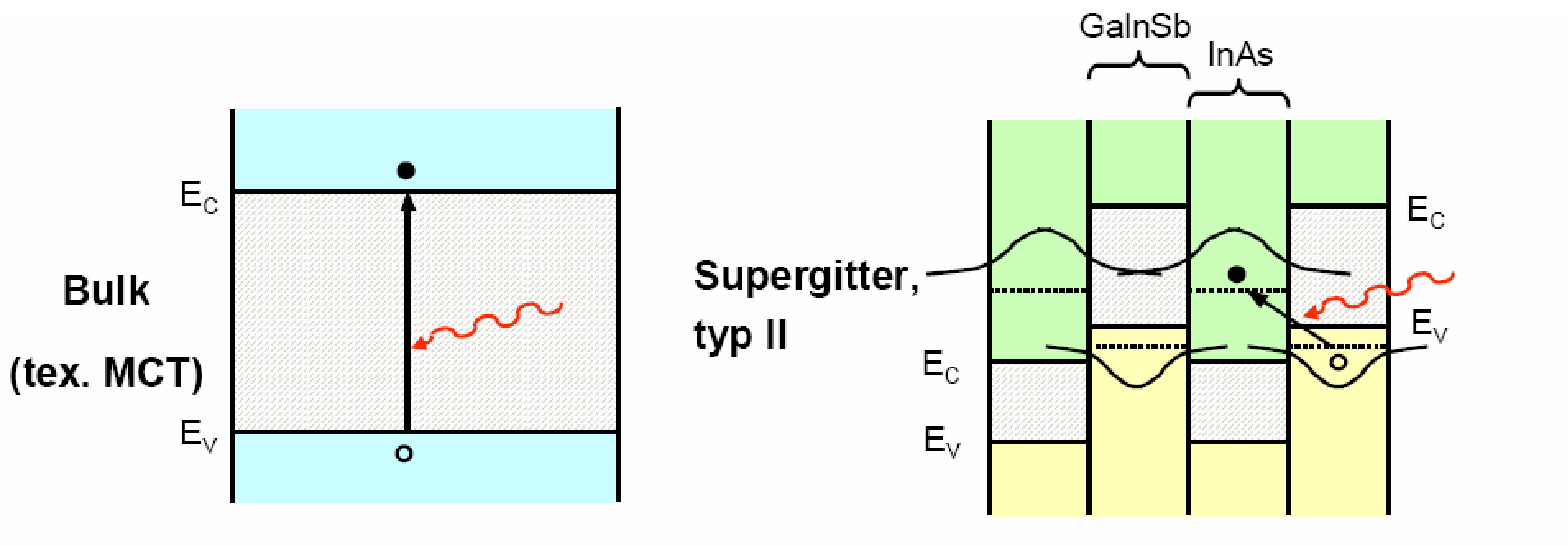
High sensitivity

High uniformity across wafer => high yield

The wavelength can be tailored between 3-20 µm

80 K operation temperature

**Possibly better performance than MCT**



# InAs/InGaSb superlattice detector (Sb-SL)

A detector optimised for the MWIR range has a response of about 1.1 A/W corresponding to 35% quantum efficiency.

Structure grown by MBE

Work on matering the leakage current problem for LWIR is currently working on

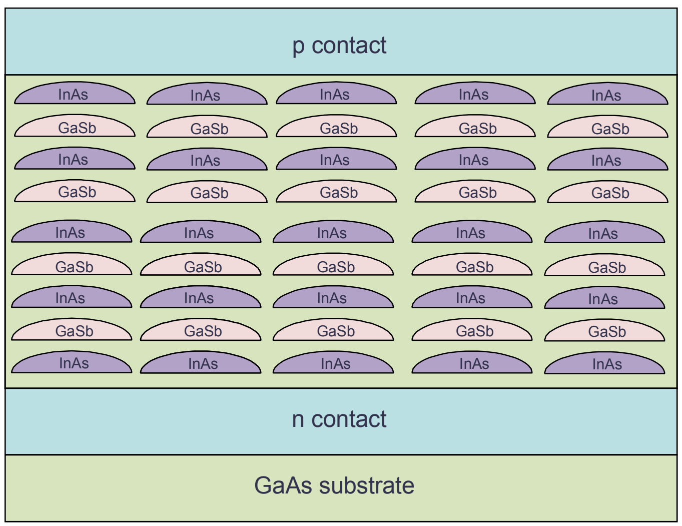
- mesa regrowth of high bandgap materiel

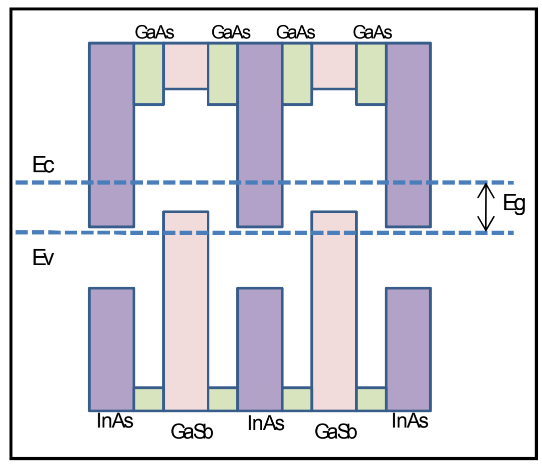
# Sb-QD-SL

Antimony based Quantum Dot structures

**Advantages => higher performance due to:**

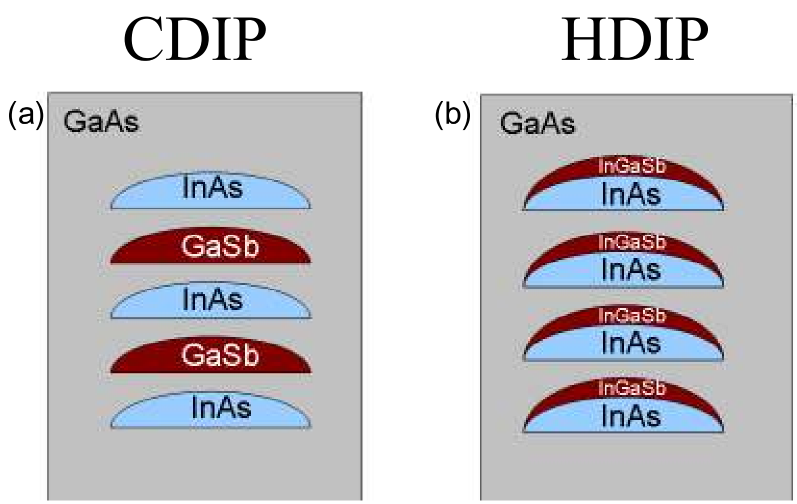
- Can be grown onto cheap large area gallium arsenide substrates
- Reduced problems with surface leakage currents

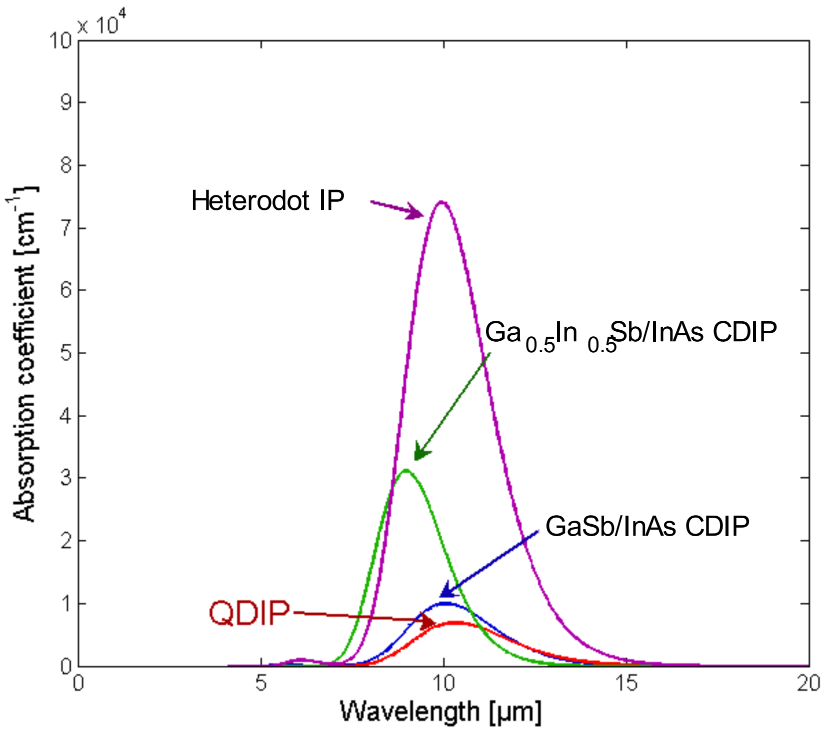


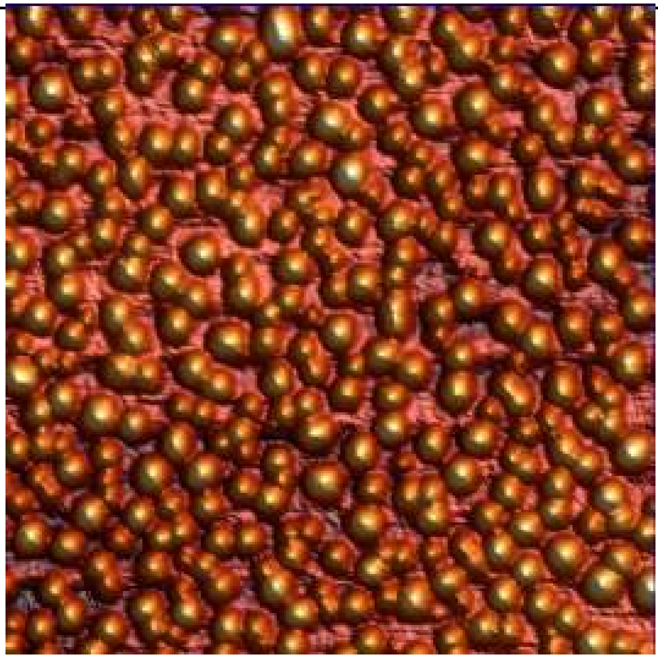
## Results: QD SL

From simulation we have two concepts that would give high response in the LWIR area.
8-band k·p including strain



# Results: QD SL AFM



1x1 µm

GaSb-dots, density 4E10 / $cm^2$

1x1 µm

InAs-dots, density 3E10 / $cm^2$

- Optimisation of InAs and GaSb QDs, separately (GaAs substrate)
- InAs/GaSb dot on GaAs

## Results so far

A type II transition has been observed experimentally but at NIR wavelengths (not LWIR)

The GaSb dots seem to contain large amounts of arsenic due to intermixing

We are trying to get around this problem in various ways

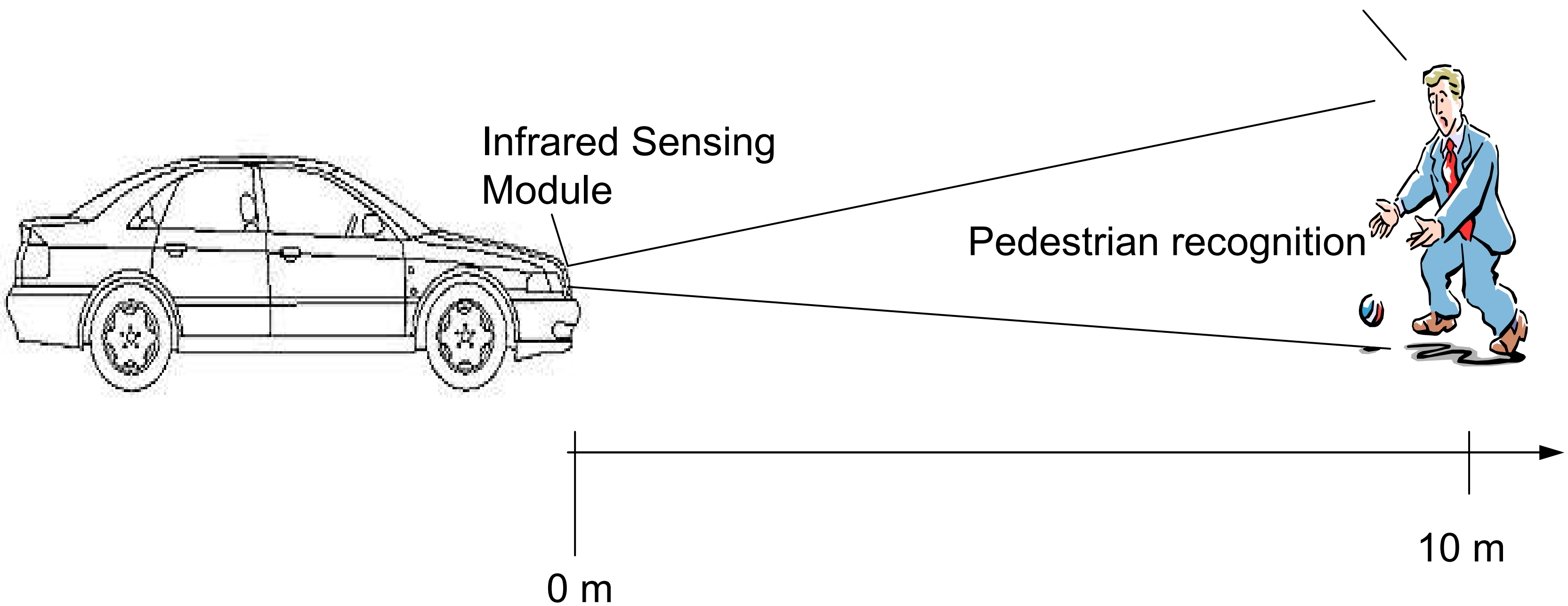
# Low-cost (uncooled) infrared microbolometers

# Automotive night vision

**PIMS = Pedestrian Injury Mitigation System**

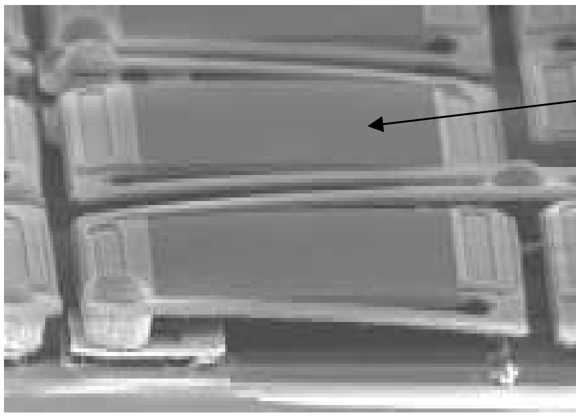
Development of low-cost IR arrays for detection of pedestrians

Cooperation with Autoliv Inc.



# Uncooled IR detectors: microbolometers

Uncooled IR detectors for night vision and collision avoidance in cars



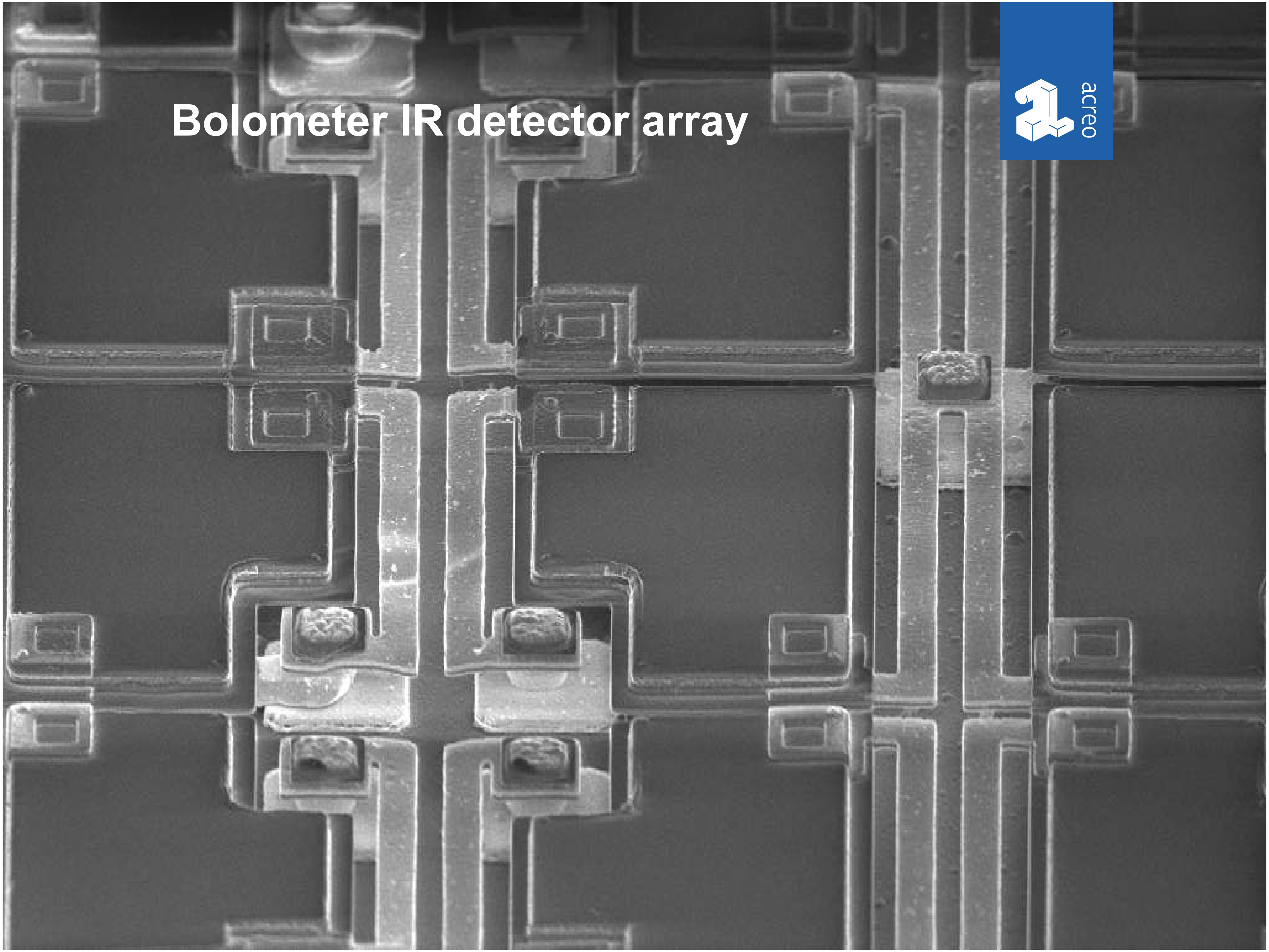
Thin membrane heated up by impinging IR radiation

Based on micromechanics in silicon (MEMS – Micro Electro Mechanical Systems)

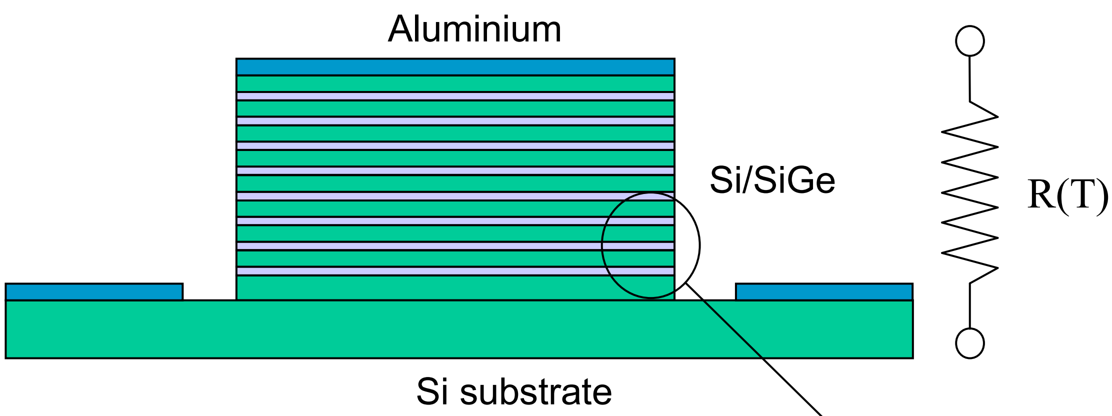
*Technical challenges:*

- Micromachining based on adhesive bonding (Collaboration with KTH)

# Bolometer IR detector array



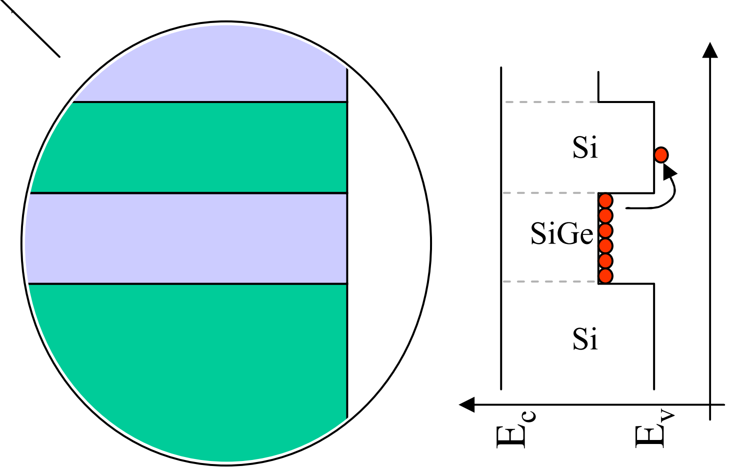
# Thermistor bolometer




A thermistor is a semiconductor based, temperature dependent resistor. The warmer it gets the lower the resistance.

Material system:

**Si/SiGe** valence band p-doped quantum wells

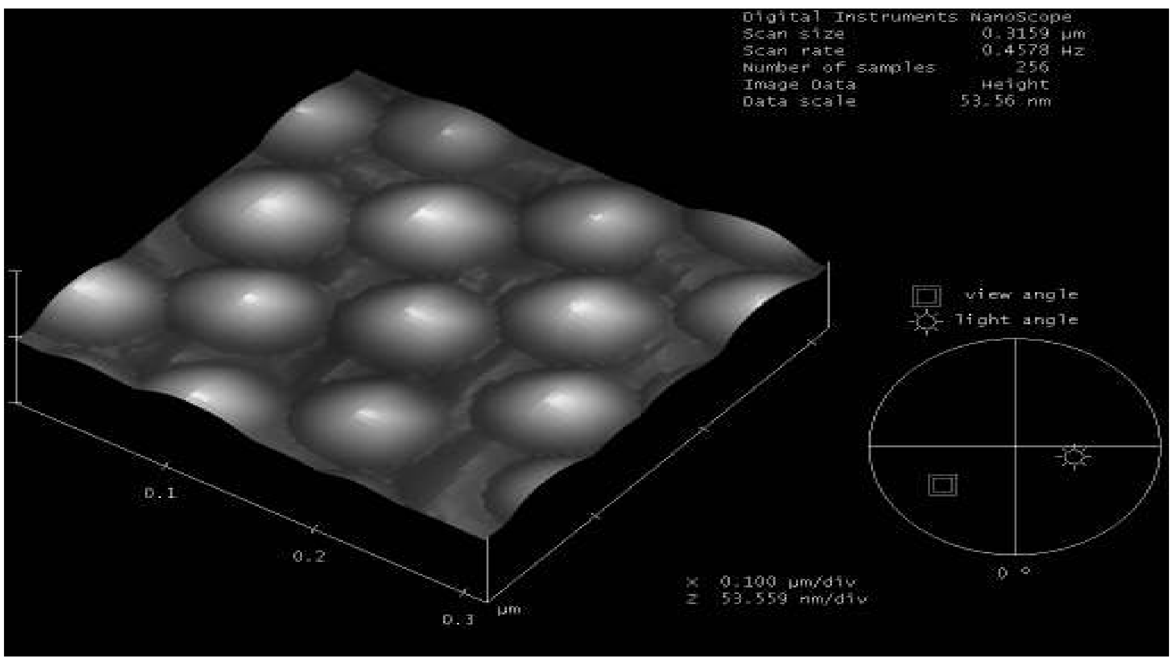


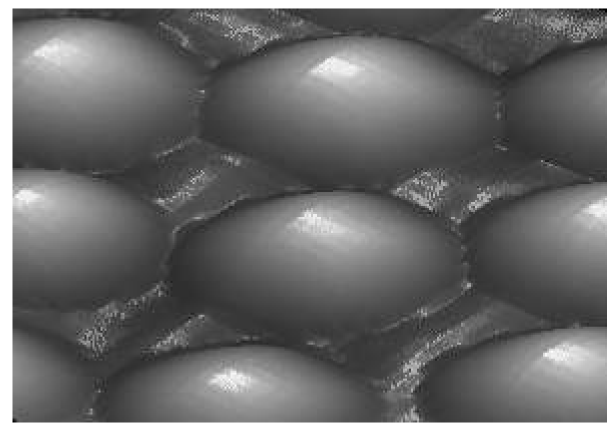

**Results so far: temp coeff =3.5%/K**

**Monocrystalline: low noise**

# Dots

## Development of thermistor material based on Si/Ge island/dot structures



# Summary SiGe/Si thermistors

- Thermistor material with TCR = 4.2 %/K achieved
  - Most common material VOx TCR = 2-3 %/K
  - Si/Ge quantum wells TCR < 3.5 %/K

- Quality of QDs:
  - High uniformity
  - High density
  - High germanium content

- Good knowledge of production process

## Summary

Acreo – the industrial research institute within optics – electronics – communication technology

The Center of Excellence IMAGIC – IMAGing Integrated Components

**Goal: the development and realisation of next-generation digital imaging systems for non-visible wavelengths**

Long-term experience on IR arrays, esp. QWIPs and microbolometers (based on SiGe). R&D on other types of IR arrays: QDIPs, InAs/InGaSb SLs,

# Thank you for your attention!

# END